Complex electronic voting systems. Adaptation to multi-choice distributed environments.

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Summary
An on-site electronic voting system is analyzed for distributed environments, with multiple simultaneous election models and different types of voters, used for periods longer than one day and with real-time counting of votes.
This type of complex study cases is related to requirements of the UNLP combining various organizational levels (professors, assistants in charge of assignments, graduate aides, external graduates, students, and non-teaching staff) in elections where each of these groups has different characteristics and representations for governmental bodies: Assembly, High Council, Boards of Directors and Students Government Associations at the different Schools.
Representation is different, among other aspects, in relation to numbers and the ways in which majority and minority are expressed.
These functional complexities are added to the geographical distribution context of the election locations, with several Schools having regional centers in the Province of Buenos Aires, and the duration of the elections, since they typically take place in periods ranging from one to three days.

Key words: electronic vote, distributed environments, multi-election model.

1 Introduction

A voting system is an information system. The voting instance (the specific point in time when the voter makes his or her decision and specifically in relation to the idea of *electronic vote*) is one of the subsystems within a larger system that encompasses the entire voting process (from the generation of electoral registers to counting the votes and grouping individual decisions). [1]

As in any information system, the first stage is necessarily the analysis and determination of the requirements that will have to be met. This analysis reveals that voting systems can be considered as critical systems.

The use of some electronic vote technology implies as a prerequisite the analysis and adaptation of current laws to consider the change in methodology, keeping the goals and warranties inherent to any voting process.

Even though the election act usually plays at a central stage on voting days, there is a large number of tasks that have to be carried out to ensure its efficiency, transparency, security and auditability.

The election process can be divided in three well defined stages: pre- and post-electoral processes and the election itself. These three stages *are present in any election model.* [2]

Pre-electoral processes include the definition of the type of election, the positions that are part of the election, the candidates for those positions, the definition of the computational centers, their geographical distribution and that of the voting centers, the creation of electoral registers, electoral service query services, appointment of authorities, etc.

The election stage can in turn be subdivided into three sub-stages:

1- Opening of the election, which involves precinct board members verifying the state of the ballot box and the validity of the electoral register and the candidates for the positions, sealing the ballot box and issuing the opening record.
2- Voting, where the precinct board members must verify voters' IDs and check that they vote.
3- Counting the votes, which involves, once the voting stage is finished, the precinct board members counting the votes, recording the results using some sort of system, and issuing a closing record which is typically communicated to the corresponding computation center. Once the results are received from the voting centers, the computation of the total is carried out and the winning candidates are communicated.

After analyzing various voting processes, it can be seen that there are in principle different types of elections: [3]

- From an operational standpoint, there are *"closed daily loop"* elections, which start and end with no interruptions, usually on the same day, and include the activities of voting, ballot box closure, and vote counting. A different model, *"several day loop"*, is carried out with partial voting periods without partial vote counting (in general, throughout several days), and a final closure with the corresponding total vote counting.
- From a functional point of view, there are *single objective* elections (for example, an election that includes only a presidential ticket or referendum elections for YES or NO), and *multiple objective* elections (for example, elections that include national legislators, provincial legislators and school counselors) that may have conditional authorizations for electors (e.g., foreigners).

In the case of electronic votes, there are various models that can be used, each with its own particular characteristics. Modern voting systems can be classified as: [4]

- *Remote voting systems (digital vote)*: this can be done over the Internet, personal computers, mobile phones, among other devices. The vote is sent

through a communications network, from the location where the vote is cast to a "remote digital ballot box", or central server.

- *On-site voting systems (electronic vote)*: this is done through specific machines and programs that are not connected to the Network of Networks. In this case, voters must go to the traditional voting locations to cast their vote using these electronic machines. This model can in turn be classified as:
  - *Optical Scan Voting (OSV) Systems*: these systems continue to use paper ballots as main instrument to cast votes, and use a counting device to identify the ballots and record the corresponding votes, and then tally them in machine memory.
  - *Direct Recording Electronic (DRE) Voting Systems*: these systems use electronic and/or digital instruments as essential tool to cast votes. There are a few variations available, such as: recording the votes in the memory of the voting device by means of a keyboard or a touch screen, recording the vote by means of an individual magnetic band card and scanning it on a separate machine, recording the vote in the memory of the voting device and printing out a paper ballot.

The main contribution of this paper is based on analyzing and developing a customizable software application for various types of elections that allows processing multiple simultaneous elections carried out from various physical locations.

2 Significant aspects of the electronic vote software.

The software model used for elections with electronic votes should consider all essential elements and procedural steps of the corresponding electoral regime [3] [5] [6]. A possible solution poses two scenarios: precinct board members that interact through the "Precinct Board Members Terminal" and the "Electronic Ballot Box" that is built, programmed and located so as to replace the classic "Voting Room" and whose purpose is allowing voters to select among a series of alternatives based on their electoral profile and with all applicable voting privacy warranties. Figure 1 shows the interaction between both system components and voters.

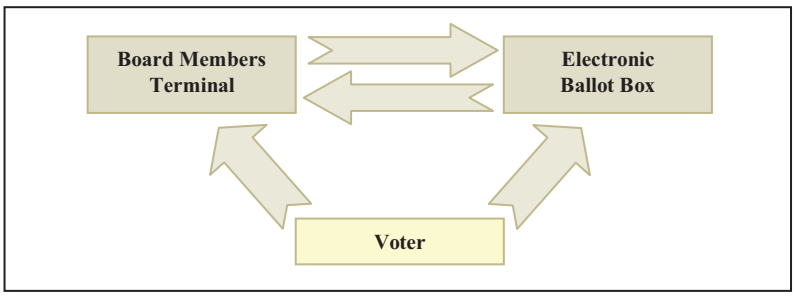

Fig. 1. Model of the interaction between participating entities.

When voters appear before the precinct board members, the President of the precinct enters the voter's ID Card number on the Precinct Board Members Terminal,

checks the information and, if valid, enables the ballot box for the voter to vote. Once enabled, the voter faces the electronic ballot box to cast his or her vote; while this is done, the Precinct Board Members Terminal is disabled. When the voter confirms his/her vote, the Terminal informs The President of the precinct that the voter has finished. This procedure allows ensuring that the vote has been cast, since the President of the precinct has to withhold the voter's ID card until the vote is cats or the voting time finishes and the attempt to vote is cancelled.

Once at the electronic ballot box, voters will face the possibility of choosing among all available options for that given election, for instance, if the election includes candidates for more than one type of positions, voters will be able to opt between voting a full list of candidates (i.e., voting all candidates from the same list for all positions), splitting tickets (i.e., selecting a candidate for each particular position from any of the available lists), or casting a blank ballot. Upon confirmation of the vote, the ballot box issues a ticket with the detail of the vote that falls into a physical ballot box that is sealed; this ticket is used for subsequent of the electoral process.

Throughout the election, the President of the precinct can access a series of control and verification options, such as checking the number of votes that have been recorded so far. When the electoral process finishes, the President of the precinct closes the election. After confirming the closure of the election, a series of options is shown to see the results, for instance, see winners, detail of votes by position, print closing records, and so on. After viewing the results, the election cannot continue.

With the election closed, the machine is turned off and a device containing the information of all votes cast at that booth is handed in to the authorities in charge of its transportation to the corresponding computation centers, together with the ballot box that contains the physical ballots, if necessary.

To model this set of activities, several stages of the process are presented: “initial stage,” “election stage,” “voting stage,” “results stage,” and so on. Each of these has a different number of operations that have to be carried out.

Some non-functional requirements that should be considered by the software are: the system has to be flexible (it has to be capable of accommodating different election models), auditable (from the perspective of software levels and the results recorded at each booth), friendly (the system has to be easy to use even for those who are not used to computational tools), and reliable (available, reliable, secure and protected).

3 General description of the electronic voting system developed since 2007

Based on the set of conditions mentioned above, a voting structure that has, for each election precinct, a computer for precinct board members (*Precinct Board Members Terminal*) connected to a voting machine (*Electronic Ballot Box*) was developed. One of these machines is shown in Fig. 2. Precinct board members are in charge of identifying voters (through the presentation of an identity card with a picture or student picture ID) from the electronic electoral register stored in the machine, which then transfers the corresponding authorization to vote to the voting machine. After the

vote is cast, the voting machine transmits a signal to the terminal used by the precinct board members so that they can continue with the process. [7]

Each electronic ballot box is a kiosk-type structure containing: a standard PC, an LCD touch screen, a thermal printer, a storage ballot box for printed tickets, a device that allows viewing the vote and that automatically drops printed tickets into the sealed ballot box, 2 flash memories where vote counts will be stored, and one UPS for any eventual energy blackouts. This machine communicates only with the terminal used by precinct board members through an RS232 connection.

On the other hand, each precinct terminal is a portable PC with minimum requirements and open source base software connected only to the electronic ballot box.

When the voting period is over, votes are counted on a separate machine prepared for this purpose. Results are transferred through the removable memory devices mentioned above (2 per session, one of them used as backup), which are stored in a wax-sealed envelope at the closing of each session, together with the ballot box containing the printed voting tickets.

Fig. 2. Electronic ballot box used since 2007

4 Election model at the UNLP as from 2010.

The UNLP has modified its Statutes [8], considering 6 organizational levels to be represented in the government of Academic Units and the University: Professors, Assistants in charge of assignments, Graduate aides, External graduates, Students and Non-teaching staff. Each of these organizational has its own characteristics and representatives in the various governmental bodies of the University (Assemblies and High Council of the UNLP and Board of Directors at each of the 17 Schools). For this reason, is a general system is to be used, its programming must be adapted and made flexible.

In the following sections, the specific election characteristics for each organizational level (or subset thereof) are explained, emphasizing the student level due to its greater complexity (voter volume, voter categories, representation of the majority and up to two minorities, among other particular characteristics).

4.1 Characteristics to consider for professor elections at the UNLP

When electing Professors, seven representatives are elected for the Board of Directors/University Assembly, and one for the High Council. The first group can be formed by five representatives from the list obtaining the majority of votes, and two from the first minority (if it gets at least 25% of the votes). [8]

Elections occur every four years, and an only position is elected, "*Professor Representatives*," that includes the representatives for both the Board of Directors and the High Council.

The election spans over a period of three days and ballot boxes are changed daily; at the end of each day, they are wax-sealed and locked in a storage space. When the election finishes, votes in all ballot boxes are tallied.

Electoral authorities are formed by an Electoral Board and, for each voting precinct, one Professor acting as Precinct President, one Assistant in charge of assignments or one Graduate aide or one External graduate, and one Student. There is also an Oversight officer from each of the lists.

4.2 Characteristics to consider when electing Assistants in charge of assignments, Graduate aides, and External graduates

The election of these three organizational levels is specific because each of them chooses its own representative for the Board of Directors/University Assembly through separate electoral registers, but they choose a single joint representative for the High Council through a unified electoral register. [8]

These elections are also held every 4 years, and they are carried out simultaneously because of the election of the joint representative for the High Council.

The election spans over a period of two days and ballot boxes are changed daily; at the end of each day, they are wax-sealed and locked in a storage space. When the election finishes, votes in all ballot boxes are tallied.

Electoral authorities are formed by an Electoral Board and, for each voting precinct, one Professor acting as Precinct President, one Assistant in charge of assignments or one Graduate aide or one External graduate, and one Student. There is also an Oversight officer from each of the lists.

4.3 Characteristics to consider for student elections at the UNLP

Student elections at the UNLP take place on a yearly basis and have a duration of three days. Ballot boxes are changed daily; at the end of each day, they are wax-sealed and locked in a storage space. When the election finishes, votes in all ballot boxes are tallied.

In this case, students vote for two types of authorities or positions: representatives as student faculty members (voters are those who comply with regularity conditions), and/or authorities for the student government association (any student in the electoral register may vote). The electoral register indicates which type of votes students are enabled to cast: STUDENT GOVERNMENT ASSOCIATION ONLY or FACULTY AND STUDENT GOVERNMENT ASSOCIATION.

The student faculty authorities elected are: five representatives for the Board of Directors/University Assembly, and one for the High Council. The first group can be formed by three representatives from the list obtaining the majority of votes, and one representative from each of the first two minorities (if they get at least 20 % of the votes). These candidates are elected for the single position of "*Representatives of Student Faculty*" that includes the representatives for both the Board of Directors and the High Council [8].

The electoral register is divided in electoral precincts. Ballot papers are divided in two sectors (student faculty authorities – student government authorities), and students can vote sections from different ballots.

Another characteristic of these elections is the existence of students that appear more than once in the electoral registry (they are enrolled in more than one Academic Unit). These students can vote for student government association authorities at each School in which they are enrolled, but they must chose at the University (if they comply with regularity conditions in more than one School) one Academic Unit where they will vote for student faculty representatives.

Electoral authorities are formed by an Electoral Board and, for each voting precinct, one Professor acting as Precinct President, one Assistant in charge of assignments or one Graduate aide or one External graduate, and one Student. There is also an Oversight officer from each of the groups.

4.4 Characteristics to consider for non-teaching staff elections at the UNLP

The election of Non-teaching staff also has its specific characteristics, because each Academic Unit chooses a representative for the Board of Directors who, unlike the representatives from the other organizational levels, does not take part in the University Assembly. Also, from among all Non-teaching staff members of the University, 10 representatives are chosen for the University Assembly and two for the High Council. [8]

From a practical point of view, voters vote for two different positions: "*Non-Teaching Staff Representatives at School Level*" (Board of Directors) and "*Non-Teaching Staff Representatives at University Level*" (University Assembly and High Council).

These elections are held every four years and span over a period of one day. When the voting period ends, votes are tallied and the results of the election for University Assembly and High Council representatives are submitted to the University, where the final tally of all Academic Units and other University dependencies is done.

Electoral authorities are formed by an Electoral Board and, for each voting precinct, one Professor acting as Precinct President, one Assistant in charge of assignments or one Graduate aide or one External graduate, one Student, and one member of the Non-teaching staff. There is also an Oversight officer from each of the lists.

5 Need for complex electronic voting systems.

As discussed in the previous sections, each of the elections carried out at the University has its own specific characteristics that have to be taken into account when

developing an Electronic Voting System adaptable to the various voting scenarios. Some considerations arising from this analysis are:

- More than one type of election can take place simultaneously to leverage the effort required to organize any electoral process, for example, Student and Non-teaching staff elections could be carried out at the same time. In order to be able to use the same voting machines, the system should not only be easily adaptable to each case, but it should do so automatically based on the voter that is about to cast his/her vote.
- The same voting machine can be used to cast votes from various Academic Units. For instance, the combination of elections whose numbers of voters are not large enough to justify the effort of implementing an electronic voting system if done separately. In this case, even though the behavior of the system is the same for voters from different Academic Units, it must be adapted to present different ballots (or candidates) based on the affiliation of the voter.
- In the case of student elections in particular, the electronic voting system must take into account the right of each student to vote in more than one Academic Unit for student government association authorities (but not so for Student Faculty representatives).
- Similarly, the possibility of voters being distributed in various dependencies must be considered, which means that the electoral process cannot be carried out in a centralized manner. This particular situation has to be taken into account when tallying the votes, since the results from all dependencies must be combined to obtain the final result. The following examples can be mentioned: elections at an Academic Unit with dependencies in several cities, and the election of representatives for the University Assembly and the High Council for Non-teaching staff.

The electronic voting system developed should take into consideration all these combined situations throughout its development stages to render a model that is fully flexible and automatically adaptable based on the needs of the election and each particular voter.

6 Adaptation to multi-choice distributed environments.

To meet the needs mentioned in the previous section, the electronic voting system that was being used is modified to accommodate these distributed, multiple-election environments.

6.1 Generalization of the electronic voting system.

In a first stage, the system is generalized to include the specific characteristics of each type of election, but without modifying the software and/or hardware used.

To do this, a customizable model is generated where an *Election Instance* is defined to indicate the positions that are being voted for and the set of lists (or candidates) for each of these positions.

Then, based on voter conditions and/or characteristics, the list of positions for which each voter can vote is indicated on the electors register located at the terminal

used by the authorities. Thus, when the voter is identified, the electronic ballot box automatically enables only those positions for which the voter can vote.

6.2 Possibility of multiple joint elections.

As a second challenge, there is the need of carrying out more than one election at the same time using the same machines.

This requirement can be easily met by allowing the definition of multiple *Election Instances* in the model, each with its respective positions and lists (or candidates).

From the point of view of the terminal used by the authorities, a single electronic electoral register is used that includes every voter with an attribute indicated by the *Election* to which the voter belongs. This, together with the list of positions that can be voted for based on voter conditions and/or characteristics, allows, upon voter identification, enabling the electronic ballot box for the corresponding election and positions.

This decision is useful also to meet the requirement of carrying out elections from more than Academic Unit or University dependencies using the same voting machine. For each of these elections, a different *Election Instance* is defined with its own positions and lists. In the case of student elections, in which the same voter can vote for candidates from different Academic Units when voting for student government association authorities, the electronic register lists such voters more than once (one for each possible Academic Unit).

6.3 Distributed tallying.

Finally, the problem of having geographically distributed voters (or separated by any other characteristic in particular) has to be solved.

At this point, the use of the Internet to cast electronic votes can be considered. This solution involves implementing a number of precautions regarding security and network operation. Also, there should be some means to ensure voters that their votes have been effectively tallied. Lastly, if the dependencies are on the same hierarchical level, one of them will have to be selected as the *Central Dependency,* responsible for keeping voting machines, while voters in the remaining dependencies will use the Internet to vote. [4][9]

To avoid the inconveniencies mentioned above, the electoral process is carried out independently in each dependency by means of the electronic voting system; and each dependency is responsible for tallying its own votes. When partial results are known at each dependency, they are communicated to a central repository that is managed by the Central Electoral Board responsible for obtaining the final results.

The communication method used to send the partial results from each dependency does not require any type of special precaution in relation to security and ensuring continuous operation. If a communication fails, it can be re-sent as many times as necessary, even using a different communication method (for instance, e-mailing the results). On the other hand, any interference with and/or modification of the message including these partial results can be easily detected, since results are public, at least in the dependency of origin.

7 Conclusions and future lines of work

An analysis of a multi-election electronic voting system oriented to distributed environments has been presented.

The development of the interface and the functional response of each local system are adapted to the user profile in each electoral register.

Previous experiences with elections carried out at the School of Computer Science of the UNLP (for various organizational levels) has allowed testing the equipment and software solutions proposed in this paper.

Contextual difficulties have been described (election duration, voters with different attributes, tallying, and different representation based on legislation). Similarly, the reasons for not using a system that is entirely based on the Internet have been detailed.

The system is being partially tested in 2012, and a set of 6 machines is being assembled to test the environment as a whole.

Future lines of work within the ongoing e-Government project are focused on the use of biometric identification technologies and mobile technologies for various electronic government applications, as well as the aspects to be taken into account to enable the use of terminals by people with different abilities.

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